

## Abstract

River Ganga is considered holy by the people of India and it supports a population of more than 440 million people. A significant source of emerging contaminants (ECs) entering the river is sewage, industrial waste, and agricultural runoff. The present study was conducted for monitoring and assessing the risks of ECs including antibiotic resistant bacteria (ARB), antibiotic resistant genes (ARGs), pharmaceutical and personal care products (PPCPs) and heavy metals) in the water and sediment samples at 16 sites of the river Ganga. The estimation of abundance and identification of ARB present in water and sediments samples of the sixteen sites of the river Ganga were conducted. Six different antibiotics were used for estimating the abundance of ARB. A diverse phylogenetic group of ARB was obtained at all the sites, comprising 54 genera, including 13 opportunistic pathogenic genera, except G1 and G2. Further, the bacterial community analysis of sediment samples showed the presence of potentially waterborne pathogenic genera and species throughout the entire stretch of the river except for the sites G1 and G2. It also indicates that the bacterial core community remains the same, but their abundance varies among the sites. In this study, 20 clinically significant ARGs and 15 PPCPs and endocrine disrupting compounds (EDCs) were also estimated. Risk assessment was carried out for the exposure of heavy metals, ARB and PPCPs.

Pollution indices such as geo-accumulation ( $I_{geo}$ ), enrichment factor (EF) and potential ecological risk index (RI) were used to assess the contamination level of the river at various sites. The human health risk was also evaluated for each heavy metal in terms of non- carcinogenic and carcinogenic risks. The  $I_{geo}$  indicates the extremely polluted condition at site G8 due to chromium and cadmium. Similarly, EF is also higher at site G8 for chromium and cadmium. RI indicates that the G8 and G16 were in the category of high and considerable risk in winter. However, in summer RI for the site G8 and G9 were in the category of considerable risk. The total non-carcinogenic risk for adults and children was mainly due to arsenic and chromium for water and sediment exposure, respectively. The carcinogenic risks for all the metals were in the negligible to an acceptable range for water exposure in adults and children. However, sediment exposure poses a carcinogenic threat for children due to high chromium at site G8. Quantitative microbial risk assessment (QMRA) was used to estimate the probability of infection due to ARB present in various sites. QMRA suggests that the abundance of *Pseudomonas aeruginosa* and *Enterococcus faecalis* in the sediment samples and *Escherichia coli*, *Enterococcus faecalis*, *Aeromonas hydrophilia*, *Pseudomonas aeruginosa*, *Klebsiella pneumonia* and *Staphylococcus aureus* in water samples can probably cause 10–4 infections per person per year when water and sediment are consumed. Ecological and human health risk assessment was also estimated for PPCPs. Based on ecological risk assessment, triclocarban and diclofenac pose a higher risk for an aquatic organism (fish) in the river water column, whereas triclosan and metformin show moderate to high risk in the sediment column. However, negligible risk of PPCPs was observed for humans except for 17 $\alpha$ -ethynylestradiol.

This study shows the widespread distribution of ECs and associated risk due to these ECs, throughout the river Ganga. The ECs are more abundant at the human impacted sites, indicating that the different anthropogenic activities increase the level of ECs in the river Ganga. There is a considerable variation in the concentration of heavy metals, ARB, ARGs, PPCPs and EDCs in water and sediment samples among all the sites. This variation may be due to the change in the volume of sewage and industrial waste being discharged to the river at different locations. The information gathered in this study can be used to indicate and recommend some important actions and policy suggestions for the protection of the river and the health of its users.